ear. The left temporo-mandibular joint was exposed; bony ankylosis was found between the mandible and the temporal, and the head and neck of the mandible were removed by chisel and gouge. Free movement was immediately obtained, amounting to one inch between the incisor teeth. Subsequently this movement was maintained by the daily insertion of a gag.

At the present date, two and a half months after the operation, there is still a full inch of movement and the child can eat in a normal manner.

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ON

THE PLAGUE.*

BY

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III.—THE EPIDEMIOLOGY OF PLAGUE.

EACH species of flea generally selects its own species of host, hence the designations human flea, dog, cat, or rat flea. But this method of naming fleas is not strictly accurate, though often convenient. There are, for example, some thirty to forty different species of fleas found on rats in different parts of the world, but our knowledge of them is still very incomplete. With the warning, then, that my remarks on fleas may apply to a number of closely related species, I can proceed to explain that the same species of flea may be found on a number of hosts. *Xenopsylla cheopis*, for example, has been taken on cats, rabbits, guinea-pigs, kangaroos, an Indian antelope, men, and on a number of species of rats. Other species are more restricted in their choice. Different species of fleas also differ in respect to the length of time they live upon their host. Some species fix themselves more or less permanently to one particular host, other species for short periods only. Some feed at frequent intervals, while others drink deeply but less often. All these traits influence the power of any particular species of flea to convey plague from one animal to another. We may conclude that although the transmission of plague by fleas is a purely mechanical process, and for this reason quite different from the transmission of malaria by mosquitos, yet the successful transmission of plague depends to some extent on the species of flea which serves as the transmitting agent.

It is remarkable how speedily fleas can reach a host which comes within a short distance of the spot where they lie in wait. A few examples will suffice to illustrate this peculiar trait, which is of much significance in the spread of plague.

I remember well visiting a commercial office in Bombay where two dead rats had been found in a corner of a very large room. One of these rats was examined and proved to be infected with plague. On the evening of the day on which the rats were found two guinea-pigs were allowed to run free in the corner of the room where the rats were said to have been picked up. The movements of the guinea-pigs were restricted by a barrier which confined them to a portion of the room only. Early next morning a dead rat was found on the floor outside the barrier which confined the guinea-pigs; it lay beneath the desk of one of the clerks employed in the office. The rat was examined for fleas as soon as it was found; six were caught on it. Nothing could be seen on the spot where the rat had died, but a guinea-pig, which was known to be free from fleas, was allowed to run backwards and forwards over this area for about one minute. It was then chloroformed and searched for fleas; eighty-two were picked off it. A second clean guinea-pig was allowed to run over the same spot while the first was being examined; thirty-two fleas were taken on this second animal. Twenty-nine of the 114 fleas caught in this way were dissected; seventeen of them showed abundant plague bacilli in their stomachs. The remaining fleas were transferred to a fresh guinea-pig in the laboratory, and it died of plague in four days. Neither of the guinea-pigs which had been used to trap the fleas developed plague.

We can form some idea of what might have happened to these rat fleas if the clerk had taken his place at his desk, and if the guinea-pig flea traps had not been used, from the following experience in another part of the town. Here a long building, divided into a number of small rooms by partitions, had been evacuated recently by the inhabitants because of the outbreak of plague among them. We visited this house on April 17th with an Indian coolie assistant. This man had bare legs; he entered one of the empty rooms for a few seconds, and when he came out his legs were examined. Forty fleas were captured on his legs; all were human fleas. Next day, April 18th, the place was again visited, and the same thing happened. On this occasion 113 fleas were caught on the man's legs; fifty-five of them were human fleas, fifty-one were rat fleas, and seven were cat fleas. On the third day the experiment was repeated, when forty human, thirty-four rat, and two cat fleas were taken. On the fourth day the yield was eighty fleas (eighteen human, sixty rat, and two cat fleas). Observe that, at first, only human fleas were caught, but later, when the rat fleas had cause to seek another host in the absence of living rats, rat fleas were captured together with human fleas on the coolie's legs. By the fourth day more rat fleas than human fleas were taken on the man. It is quite possible that, had we not examined this man's legs and removed the fleas from them, he might have carried some of these fleas to his home, and there they might have transferred their attention to their natural hosts the rats.

These observations show that infected rat fleas do not travel far from the spot where they left their host; they generally lie in wait for the passing of another host. If this new host is a rat, the fleas are readily attracted to it and may then be carried to a distance limited by the extent of the rat's wanderings. If the new host is a man, then the distance over which the fleas can be carried may be considerably greater, and will be limited by the distance and by the speed at which the man travels.

Plague thus progresses in two very distinct ways: first, to contiguous areas—here infection is carried chiefly by rats; secondly, to more distant centres *per saltum*—in this case infection is transported by men. Men may carry rat fleas either on their person or in their clothing, or they may transport rats and their fleas with merchandise, in which case railways and ships materially assist the dissemination of the disease.

The Plague Commission was able to shed some light on the probable course of an epizoötic of plague among rats when men did not take part in the dissemination of the disease. The progress of epizoötics which were induced in groups of rats confined in godowns infested with rat fleas was studied, and the progress of an epizoötic in a village which had been abandoned by its inhabitants and in which guinea-pigs were substituted for the human population was observed.

The godown experiments were carried out in Bombay in succession throughout a whole year. They showed that the severity of the epizoötic depended on the number of fleas present in the godowns, and on the degree of septicaemia developed in the infected rats. A certain number of rats survived the epizoötics in all the experiments, and it was impossible to rekindle the epizoötics among the survivors, in spite of repeated attempts to do so, by introducing fresh infection among them. The survivors of the epizoötics were proved to be immune to plague by subjecting them to the subcutaneous injection of virulent plague bacilli. The dose administered varied in different experiments from twelve to twenty-six thousand plague bacilli. This dose sufficed to kill a number of wild Bombay rats which were always used as controls. When the dose was small the immunity of the rats which survived the epizoötics was complete—that is to say, none died, while many of the control rats developed plague. When the dose was larger some of the survivors of the epizoötics died, but a relatively greater number of the control rats succumbed. It appeared, however, that the percentage of survivors in the two groups was not very different when allowance was made for the number of rats which had died of plague during the course of the epizoötics. The immunity of the survivors of the epizoötics did not therefore seem to have been acquired by exposure to sublethal doses. The rats which survived appeared rather to be individuals naturally immune to the disease; they had been picked out or selected by the epizoötic.

This suggested further experiments in which the immunity of rats obtained from places which had not suffered from plague was compared with the immunity of rats caught in places where plague prevailed. The first experiments of this nature were carried out in flea-infested godowns. Rats obtained from Madras, where there had been little or no plague, and rats from Bombay and Poona, where there had been much plague, were subjected in groups to infection communicated by rat fleas. The epizoötics thus induced resulted in the death of thirty-six Madras rats, three Bombay rats, and one Poona rat, out of fifty in each group. But the conditions required for the transmission of infection by fleas were difficult to regulate, so that additional experiments were designed in which subcutaneous injections

* This course of Lectures has been slightly abbreviated for publication.

of virulent plague bacilli were substituted for flea infection. The dose of plague bacilli injected was of the order used in testing the immunity of survivors of epizoötics. Employing such a dose the Commission found that from 87 to 100 per cent. of Madras rats died of plague, while approximately only 20 per cent. of Bombay rats succumbed. Repeating the experiments with large numbers of rats, we found that plague-free towns such as Madras, Raipur, Dacca, and others, all widely scattered in India, yielded rats which gave 80 to 100 per cent. mortality, while plague-stricken cities like Cawnpore, Lucknow, Poona, Bhagalpur, and others, also widely distributed over India, yielded rats highly immune to the disease. On the whole the immunity of the rats caught in these latter cities was found to be in proportion to the extent to which each place had suffered from plague.

We showed also that young rats from Bombay and young rats from Poona, caught at an age and at a time when they could not have been subjected to infection, were only very slightly more susceptible to plague than adult rats were from the same places. Immunity to plague, therefore, appeared to be transmitted from parents to offspring. The hereditary transmission of immunity was confirmed by two series of experiments in which rats bred from known stock were used.

In the one series rats bred in special godowns from wild Bombay stock were compared with wild Bombay rats, of approximately the same age, captured in the city. A dose of plague, administered subcutaneously, killed 21 per cent. of the captured rats, while the same dose proved fatal for 20 per cent. of the bred rats. In the second series rats bred from the survivors of experimentally produced epizoötics were used. Their parents had been exposed to severe infection and were therefore highly immune. That the young were extraordinarily resistant to plague was proved by the fact that only one out of twenty-five—that is, 4 per cent.—died from a dose of virus which killed 99 per cent. of Madras rats.

These experiments indicated that epizoötics of plague involve the death of susceptible rats and the survival of immune individuals. The progeny of these survivors inherit their parents' immunity. A succession of epizoötics may thus lead to the establishment of a race of rats which is relatively immune to plague.

In passing, I may be allowed to suggest that the evolution of an immune race of rats following on a long series of epidemics may explain the gaps in the continuity of epidemics which are known to have occurred in the history of plague in different countries. I have already drawn attention to these gaps in the history of epidemics. This theory appears to me to afford an explanation for the cessation of epidemics of plague in countries in which changes in the social life of the inhabitants fail to supply us with an adequate solution. It also gives us some cause to hope that the present epidemic of plague in India will in time disappear. There is, indeed, some evidence that this change is already taking place, for, not only are the rats in the plague-stricken cities relatively immune to the disease, as I have stated, but a steady decline has occurred in the mortality from the disease in some of the great cities, such as Bombay.

In the godown experiments just mentioned we were able to study the progress and issue of an outbreak of plague in a small group of rats living closely together confined in a room, but, in a village or town, the rat population is made up of a number of small groups of rats spaced out from one another in separate houses, and these conditions materially modify the issue. The Commission was therefore fortunate to secure an opportunity for studying the progress of an epizoötic among rats in a village. The inhabitants of this village, guided by previous experience, evacuated their houses shortly after the outbreak of plague among the rats, and, in many cases, they allowed us to place guinea-pigs in the empty houses. We thus substituted guinea-pigs for men in the houses and we secured the advantage of full control over their movements. When sickness and death occurred among them we were able to make careful and adequate bacteriological examinations. While we succeeded in securing conditions which were more natural than those obtained in our godown experiments, we lost considerably in accuracy and precision, for we were unable to control or examine the rats living in the village. We used guinea-pigs to indicate the progress of the epizoötic. Our experience with these animals forced us to the conclusion that they constituted a more sensitive indicator of plague infection in a house than its human inhabitants.

Infection was probably brought to this village by a woman coming from an infected house in Bombay city. She herself did not contract infection, but infected the rats in the village by bringing infected rat fleas with her. The house in which she lived was situated not far from the centre of the village, and it became the starting point of an epizoötic among the rats which progressed slowly towards the periphery. In the absence of the inhabitants the disease spread from one house to the next adjoining, and was evidently carried from house to house by infected rats. A colony of rats in one house transmitted the disease to a neighbouring colony. We can infer that in each infected colony of rats events occurred similar to those experienced in our godown experiments. A certain number of the rats died of the disease, the more immune survived. But all the colonies in the village were not infected; some escaped, so that, although the total number of rats in the village was reduced, many susceptible rats still remained. From this mixed stock, in course of time, the rats of the village were replenished.

It seems appropriate here to refer to certain experiments on the breeding of *Rattus rattus* which were carried out for the Commission in Bombay under Captain Taylor's supervision and with the assistance of Mr. Avari. These experiments enable us to understand the probable course of events in the village after the plague epizoötic had come to an end and the villagers had returned to their homes. Attempts to breed wild rats in captivity have generally been unsuccessful, and such data as were available before the Commission studied the subject referred to *Rattus norvegicus*, not to *Rattus rattus*, the species of rat mainly responsible for the communication of the disease to men.

We succeeded in rearing rats of this latter species in specially constructed godowns which afford shelter for the parent rats in artificial burrows and nests which could be exposed for purposes of inspection. Preliminary experiments in these godowns showed that rats would not breed when overcrowded—that is, when more than four pairs were confined in one godown. When many pairs lived together in the same godown no young rats were born and the females when killed were not pregnant. The most satisfactory arrangement to obtain successful breeding was to confine a single pair in each godown.

Subsequent experiments were therefore made with single pairs and a large number of young rats were bred. These experiments showed that one pair produced on an average, in one year, thirty-six young, or a litter of six, the most frequent number, every two months. In sixteen observations the average interval between any two litters was approximately fifty-three days. A pair of rats bred in the godowns gave a litter when the male was four and the female five and a half months old. Rats, however, look fully grown by the end of the third month and in nature may breed at this age. The period of gestation was from three to four weeks. More females than males were born in captivity. Sometimes the young rats were eaten by their parents, but it is possible that in our experiments more young rats were destroyed in this way than actually occurs in nature.

With these data we are in a position to gauge approximately the reproductive powers of rats. We may calculate that a single pair can produce six rats every two months, and that these young rats in their turn are able to produce young ones in four months. If a liberal allowance is made for young rats destroyed by their parents before they reach maturity, we may safely conclude that, in less than one year, a single pair can multiply to fifty pairs. As a matter of fact, observations in villages show that such a rapid increase in the rat population does not actually occur. It is probable that overcrowding, destruction by natural enemies and by disease, keep down the number. It would be wrong also to conclude that every pair of rats is always fertile. There can be no doubt, however, that rats do multiply very rapidly if they are afforded ample shelter and abundant food, so that in a village the rats destroyed by plague are replaced by breeding in the course of a few months.

Rats in Indian Villages.

Those who have never visited India can have little idea how numerous these pests are in Indian houses. In the small village of Parel, for example, where the Commission made observations, 2,195 rats were trapped in the houses during a single year. This number gives an average of fifteen rats per building. From one building which was divided into sixteen tenements, and which sheltered seventy inhabitants, as many as 393 rats were taken. At the beginning of our operations in this village sixty-five rats were captured in every hundred traps set, while at the end of the year this number had been reduced to thirty-four rats per hundred traps set—not a very great reduction. In spite of the removal from the village during the year of a number of rats equivalent to two-thirds of the human population, the number at the end of the year was apparently not very greatly reduced.

We have seen, then, that in a village plague spreads from a colony of rats in one house to another colony of rats in an adjoining house; that in this way the disease extends slowly, killing off susceptible rats in certain colonies while the more immune individuals in the colony survive. Certain colonies in the village, however, escape infection altogether, and from these colonies, as well as from the survivors of the epizoötic, the number of rats in the village is rapidly made good in the absence of any efforts on the part of the villagers to limit the shelter and food provided for the rats. The young rat community thus developed will be less susceptible to plague in proportion as they were derived from rats living in colonies which were subjected to the epizoötic. A very severe and widespread epizoötic in a small village may render that village immune to plague for a time, but a less severe or a localized outbreak in a large village or town will leave that village or town open to reinfection.

Man's Part in the Spread of Plague.

As rat fleas in certain circumstances readily take to men, they may be carried from one house in a village to another in the same village, or from one village to another. The person who carries the infected fleas may escape infection, in which case the rat fleas are transported by man from one rat colony to another. Infection was apparently carried in this way in the case of the village we have been considering. But the person who carries the rat fleas may become infected in doing so. The Commission had several opportunities to prove that this method of transferring infection from place to place does occur. For example, a woman, when moribund, was brought from an infected house in Bombay city to a house in Parel village. She died a few hours after her arrival. Her friends at once removed the body, but left behind a certain amount of clothing and bedding. Next day two guinea-pigs were placed in the room. On the following morning rat fleas were caught on them and one of the guinea-pigs died of plague. There was no plague at this time in the neighbourhood of the house.

It does not always follow that a person who contracts plague in an infected place will carry infected fleas to another place. For example, of twenty-eight cases of plague which occurred in Parel village while that village was under observation, nine were brought to the village already infected and seven contracted infection in places outside the village where infected rats had been found. We were able to prove that infected fleas were brought into the village by only one of these sixteen cases—namely, the case of the woman mentioned above. No epizoötic of plague developed in connexion with any of the cases.

If plague infection is carried by men from place to place, then, in an area with scattered villages, large villages should be more liable to become infected than small ones, and, again, places situated on lines of communication should suffer more frequently, in proportion to their size, than those more remotely situated. That this is the case was shown by Major Lamb in an elaborate and painstaking study of the distribution of plague in certain districts in the Punjab. Lamb and Greenwood also showed that the recurrence of plague in villages is explained more satisfactorily on the assumption that infection is imported into the villages by human agency than on the hypothesis that dormant infection is rekindled. Villages once infected do not, in fact, show a greater liability to become reinfected.

In a stimulating review of some facts which influence the prevalence of plague, Greenwood, as the result of a statistical analysis of the data collected by Major Lamb referring to plague in certain districts of the Punjab, drew attention to certain local differences in mortality which came to his notice. He pointed out that the virulence of an epidemic in any one district varies greatly from year to year, and that this is partly due to some general phenomenon, since the tendency is for the mortality to be high in all districts for a given epidemic, or conversely. The influence is, however, partly local, since the relative positions of the districts in respect to mortality rate are not quite the same from year to year. Further, he indicated that the mortality is not necessarily highest in that subdivision in which, judging from the number of infected villages, plague is most widely distributed.

Climatic Influences.

These features of the epidemiology of plague are common to all parts of India, and are accounted for, to a large extent, by variations from year to year and place to place in the climatic conditions, especially variations in the relative humidity of the atmosphere. The temperature and humidity of the atmosphere exert their influences on the life of fleas, and they in turn regulate the diffusion of plague. Climate may act on fleas in a number of ways.

Some species of flea have a distribution governed by climate, so that, for example, the common species of flea found on house rats in the tropics is *Xenopsylla cheopis* or one of its allies, while *Ceratophyllus fasciatus* is parasitic on this host in temperate climates. Still no accurate line of demarcation can be drawn between the distribution of these species on rats in different parts of the world, for *Xenopsylla cheopis* extends into the temperate regions and becomes numerous there on rats in the summer and autumn months, while *Ceratophyllus fasciatus* or one of its allies is found in semitropical regions, especially during the winter months. Even among the closely related *Xenopsylla* group climate influences the distribution of these species, for *cheopis* is rarely encountered in the warmer parts of the tropics, while *astia* is more prevalent there, yet both occur together in the cooler areas.

Climate not only influences the distribution of the different species of flea, but it has a remarkable influence on each species.

In Poona, for example, where the majority of the rat fleas are *Xenopsylla cheopis*, with a few *brasiliensis*, the development of eggs into larvae, of larvae into pupae and imagines, all show a marked seasonal variation. Multiplication is most active when the weather is wet and the temperature moderate, and least active under dry and hot conditions. Within the range of temperatures obtaining in Poona—that is, between a weekly mean of 70° and 85° F.—the atmospheric humidity is a more important factor than temperature in conditioning this seasonal variation. Artificial humidification of the atmosphere is favourable to all stages of development of the flea when the temperature rises to 80° F. and the relative humidity is below 50 per cent.

From the point of view of plague dissemination the effect of climate on the adult flea is particularly important, for the duration of the life of the imago is very considerably longer in a cool and moist atmosphere than under hot and dry conditions. Thus Kunhardt and Chitre, working for the Commission in Poona, showed that rat fleas can live for about four and a half times as long when the mean temperature is 80° F. and the relative humidity 75 per cent., as when the mean temperature is 84° F. and the relative humidity only 37 per cent. Bacot, working in London, has shown that fleas can live for many days unfed at a temperature between 45° and 50° F. with a nearly saturated atmosphere. *Pulex irritans* survived 125 days, *Ceratophyllus fasciatus* ninety-five days, *Xenopsylla cheopis* thirty-eight days. But at temperatures between 74° and 84° F. these fleas lived without food for ten days in a moist atmosphere, but for no longer than five days in a dry atmosphere at the same temperature. We may conclude, then, that the most favourable temperature for transporting infected rat fleas is about 50° F. when the atmosphere is damp, and that the most unfavourable temperature for this purpose is one above 80° F., or even a lower temperature, when the atmosphere is dry.

Climate therefore influences the prevalence of plague in two distinct ways. First, a moderate temperature with a low saturation deficiency promotes the activity and multiplication of fleas, so that these conditions favour epizoötic plague in an already infected place. Secondly, a low temperature with low saturation deficiency prolongs the life of a flea when away from its normal host and so favours the transfer of infection from place to place.

Infected fleas can then be carried over greater distances and can remain alive for a longer time till a suitable host is secured.

Persistence of Rat Infection.

The duration of an epizoötic of plague in a town or village will depend on the size of the place. Epizoötics in large villages will last for a longer time than those in small villages. But the season of the year when infection is introduced into a village will also affect the course of the disease. When fleas are numerous the progress will be rapid, when few it will be slow. A place infected late in one season, especially if the place is a large one, may continue to harbour infection during the hot weather; the disease then smoulders, but becomes active again as the weather becomes cooler and the fleas more numerous. In these circumstances infection is carried over from one plague season to the next.

Major Kunhardt has paid much attention to the subject of the persistence of infection in a district during the quiescent season. His studies were made in the Deccan, where the active or favourable season for plague begins in July, reaches a maximum in August or September, and then slowly declines till the end of March. The quiescent season lasts for the three months April, May, and June. He is able to determine whether a particular epidemic in a village will terminate before the close of the quiescent season or will be prolonged through that season into the next active season by considering the population of the village and the time of the year when it became infected. This is a matter of considerable importance, for he has shown that places which become infected in the succeeding epidemic derive their infection directly or indirectly from places which remained infected from one season till the next. Further, he pointed out that much labour and expense might be saved and greater efficiency obtained by concentrating antiplague measures on the places in which the epizoötic persists during the quiescent season. It is at this season that the climatic conditions assist the abolition of the disease.

For example, he showed that 276 places reported plague outbreaks during the season 1913-14 in an area of more than twenty-one thousand square miles which supported a population of nearly four million persons living in six towns and 4,442 villages; 141 of these places became infected before the close of the year 1913. He concluded that they were not therefore likely to remain infected during the quiescent period of 1914. There remained 135 places which became infected in 1914 which might carry infection to the next epidemic season. But, taking into consideration the population of these places and the month when they became infected, he excluded 112 of them as not likely to be of importance. There remained only 23 places which required attention. That is to say, he was able to state that 253 out of 273 places (91.7 per cent) which suffered from plague in that season were not likely to be the source of infection in the succeeding epidemic, so that, from the point of view of preventing the development of the next epidemic, they might be neglected. Only 23 places required special attention because any one of them might be the source of infection in the new epidemic. As a matter of fact, subsequent experience showed that only seven of the 23 places actually remained infected from the one epidemic to the next, and, in the first three months of the new epidemic season, 32 places, which had not been infected in the previous year, became infected directly or indirectly from one of the seven places which carried over infection.

If it was possible to stamp out the epizoötic in the limited number of places which retain infection from one epidemic to the next the number of villages infected in the new epidemic might be greatly lessened. Major Kunhardt, in fact, has shown that it is possible to recognize potential sources of infection, but the problem of dealing with the epizoötics in them has not yet been solved. Some work has been done, but continuous study of this important problem has been interrupted.

I can only mention here an experiment which was carried out by Dr. Strickland in 1920 on the lines indicated by Major Kunhardt. A brief account of this experiment is reported in the *Indian Medical Gazette* of January, 1923. The operations in no case reached anything like the standard which was necessary, yet the results proved that the method formulated by Kunhardt and Chitre is thoroughly effective in eradicating plague. Unfortunately the experiment was discontinued, as money to carry it on was not available.

The Commission studied the problems, which had attracted Greenwood's attention, in the United Provinces and in the Madras Presidency. They showed, for example, that the exceptionally severe epidemics which occurred in the Muttra district in the year 1904-5 with a death rate per mille of 66.8, and in the Muzaffarnagar district in the year 1906-7 with a death rate of 56.7 per mille, were associated with an unusually high percentage of relative humidity in these districts in these years. In a lesser degree the same phenomenon was observed in other districts in the same as well as in other years. Plague epidemics were severe in the years in which the saturation deficiency of the winter months was low, and those years in which the saturation deficiency was high were always years of mild epidemics of plague.

The district in the United Provinces most severely smitten by plague over a series of years is the Ballia district; it is one of the most humid in the province, especially during the quiescent plague season, so that fleas are more numerous on rats in June, July, and August there than in any other part of the province.

Plague therefore persists in a larger number of villages in the Ballia district during the quiescent season than in any other district in the province. Owing to the number of infected centres in the district at the close of the quiescent season the disease is distributed more widely and earlier in the active season, so that the epidemics are more prolonged and therefore associated with a higher mortality.

But there are other factors which possibly favour the intensity of plague in this district—for example, the villages are larger and are separated from one another by shorter distances than in many other districts, so that the density of the population is great. Then, again, the people of the district have for this reason to seek and find work in other parts of India and periodically return to their homes; communication with infected centres outside the district is therefore constantly maintained. I have drawn attention to these factors, each favourable for the development of plague, in order to point out that any one of them by itself would be of little importance. There are many districts in India where the density of the population is as great as, if not greater than, that found in Ballia, but these districts do not suffer remarkably from plague. There are other districts in which the density of the population is less than in Ballia, where epidemics of plague have been more severe. It is necessary, therefore, to bear in mind, when considering the liability of a particular place to become infected with plague, that a number of conditions must be fulfilled. This was forcibly brought home to us in our study of the conditions in the Bundelkhand, especially in the town of Banda. Here is a place where there are many rats very susceptible to plague and infested with fleas at certain seasons of the year to a degree compatible with the development of plague in other places; yet Banda had not, up to the time of our inquiry, suffered from plague. This town is situated in the Bundelkhand, where, on the whole, the climate is hotter, and particularly drier, than that of the plague-smitten parts of the United Provinces. The climate is of such a nature as to be unfavourable for the prolonged life of fleas when away from their hosts, although not markedly unfavourable for their activity and multiplication in the haunts of their hosts. Plague has been introduced into the Bundelkhand only in exceptionally humid years, but such limited epidemics as have occurred have been severe, although not widespread.

Similar conditions prevail in other parts of India—for example, in certain districts in the Madras Presidency. In these districts rats are numerous in the houses of the inhabitants; they are very susceptible to plague, and the fleas on them are not so few as to make an epizoötic impossible, but the climate is such as to decrease the chance of the transfer of infection to these places from infected centres, except in certain unusually humid years. Districts certainly are known with climates not dissimilar from one another—the Bellary and Kurnool districts, for example—which have had a very different experience of plague. This can be explained when we know that the Bellary district is adjacent to areas where plague prevails and communication between Bellary and these districts is easy and frequent, while the Kurnool district is more remote from infected centres, and has less rapid and efficient access to them.

An additional factor, which may be of some importance in explaining the freedom from plague which certain districts of the Madras Presidency have enjoyed, was noticed by Hirst in 1913, after the Commission had completed its observations there. He showed that the common species of flea found on rats in Madras is not *Xenopsylla cheopis* but the closely allied species *Xenopsylla astia*. He had failed to transmit plague from rat to rat using *astia*, while, under the same conditions, he was successful with *cheopis* in several cases. He claimed, therefore, that the freedom of certain parts of the Madras Presidency from plague might be accounted for by the absence of *cheopis* and the presence of *astia* on the rats.

I have explained that the transmission of plague by rat fleas is a mechanical process, which depends on the existence in these insects of a peculiarly constructed proventriculus which is liable to become blocked by the growth of plague bacilli in the ingested blood. For this reason all species of flea might equally well transmit plague. The Commission, indeed, succeeded in transmitting plague to guinea-pigs, not only with more than one species of rat flea, but also with the human flea. Nevertheless there can be no doubt that certain species of flea more readily transmit plague to certain animals than others on account of traits of character to which I have already referred. Major Taylor has reported recently that he has succeeded in transmitting plague from rat to rat with *astia*, though the proportion of successful experiments was fewer with this species than with *cheopis*, especially when guinea-pigs were used as the test animals. While admitting, then, that more knowledge is required of the bionomics of *Xenopsylla astia*, I hesitate to accept Hirst's explanation, especially as, in my opinion, sufficient evidence exists to show that the plague-free districts of the Madras Presidency owe their freedom from this disease to their climate. The nature of the climate at the same time serves to explain the presence of *astia* in these regions, for there can be no doubt that *astia* can thrive at atmospheric temperatures which are less favourable for *cheopis*.

Infection by Merchandise.

This method of propagating the disease comes prominently to notice in the study of plague in large towns. The members of the Commission were impressed by its importance during their investigations in Belgaum, Cawnpore, and Bombay. Major White, who was in charge of the work in Cawnpore, noted the enormous traffic in grain and seeds in that plague-infected city. In the twelve months ending February 29th, 1912, more than 260,000 bullock cart loads of merchandise, chiefly grain, entered Cawnpore by road, while more than two million maunds of grain, pulse, oil seeds, and more than half a million maunds of raw cotton came to the town by rail. "Quite a large portion of Cawnpore," he says, "can be described as one large granary." This part of the town is conveniently located to the goods yards of all the principal railway lines and consists of a large open square, round which are situated buildings, most of them two-storied. The ground floor in each case is a large grain godown or store with a small room or veranda in front which is used as an office. The owners of these stores do not live in the buildings, but there are dwelling rooms on the upper floors of most of them; these rooms are placed at the disposal of customers during their stay of one or two days in the city. Only a few of the godowns contain floors impervious to rats. In fact, from the point of view of the rat, few places could be found more generous in the matter of shelter and food than the grain godowns of Cawnpore.

The conditions in Cawnpore do not materially differ from those in Bombay. The great centre of plague in this city is the Mandvie district, situated close to the docks and to extensive railway sidings. The buildings, though often inhabited in the upper stories, are used mainly for the storage of grain, seeds, spices, gunny bags, and other merchandise—all very attractive for rats. It was in this area of Bombay that plague first gained a footing, and it has been the area from which infection has been distributed, not only all over India, but to many parts of the world as well.

In Bombay city the Commission showed that the rat epizoötic was closely related to but preceded the epidemic. The regular examination of rats, instituted by the Commission with the co-operation of the municipal authorities in 1906, has been continued uninterruptedly for eighteen years at the Parel Laboratory. The health officer of the city appreciates the value of this examination, for he is able to gauge the probable progress, distribution, and extent of the epidemic in advance. More than a million rats have been examined, thousands of infected specimens have been recognized, and, more important, hardly a day passes without some infected rats being detected, even in the quiescent season.

A centre of infection of this magnitude and persistence is not only a danger to India itself but, because Bombay is also a large seaport, it is a danger to other countries. The history of plague, I have shown, testifies to the importance of ship-borne plague in the dissemination of the disease to uninfected countries, so that the eradication of plague from large seaport towns is a matter of international importance. I agree with Major White when he states, in a memorandum published by the Government of India in 1919 and entitled "Twenty years of plague in India," that "we certainly owe it to other countries to see that the dock areas of the Indian ports are kept relatively free from rats." This should not present insuperable difficulties, for experimental work which has engaged my attention for some years proves that hydrocyanic acid gas, when scientifically generated and used, is a safe and efficient means for destroying rats and fleas, while it does not damage merchandise. If money is not available in India to carry out this very necessary preventive measure, surely it can be obtained from other sources.

REFERENCES.

[1] Reports on Plague Investigations in India, Nos. 17, 20, 23, 33, 35, 44, 45, 47, 51, 54, 55, 69, 72, 83, contained in the *Journal of Hygiene*, vols. 7 to 9.

[2] Reports of the Bombay Bacteriological Laboratory, 1907-1922, published by the Government of Bombay.

[3] Kunhardt and Chitre: *Indian Journal of Medical Research*, 1921, viii.

[4] Hirst: BRITISH MEDICAL JOURNAL, 1914, i, p. 85.

[5] Hirst: *Indian Journal of Medical Research*, 1923, x.

[6] Taylor and Chitre: Ibid., 1923, xi.

[7] Cragg: Ibid., 1921, ix; 1923, x.

[8] Liston and Goré: *Journal of Hygiene*, 1923, xxi.

Memoranda:

MEDICAL, SURGICAL, OBSTETRICAL.

THE VALUE OF TREPHINING.

I THINK the following cases of sufficient interest to justify publication.

CASE I.

A man, aged 45, whilst watching a football match one Saturday, was hit on the head but not knocked down by the ball. He went to work on Monday and Tuesday; I saw him on Wednesday, suffering from cerebral irritation. Three days later he became unconscious; in hospital he recovered, but varied between these two conditions till, on the eighteenth day, I came into the ward to find him apparently dying, with friends round his bed.

I determined to explore, and asked the nurses if they had seen any localizing sign, as I had found none. One nurse replied that the day he came into hospital he worked with the right hand. Without any anaesthetic I trephined over the left Rolandic area. On incising the bulging dura I found an extensive clot, which began to drain away. He at once began to struggle, so I replaced the bone, loosely stitched the scalp, and dressed with a biniodide compress. Next morning he was very much annoyed that he could not go home. He made a perfect recovery, which I attribute to the slow removal of the clot, this being due to his behaviour on the table.

CASE II.

A girl, aged 6 months, suffering from hydrocephalus, had been in hospital for about three weeks, growing steadily weaker, till at last she could not take food. I trephined over the occiput and inserted a double strand of catgut into the posterior horn of the lateral ventricle; some cerebro-spinal fluid escaped. I replaced the bone, loosely stitched the scalp, and applied a compress. Next day she took food, and presently was able to return home. A few weeks later she had a blow over the scar, fracturing the circle of bone, which had to some extent united, though it was only about as thick as eggshell. This caused a bulge to form in which could be felt the upturned edge of bone; this persists till the present time. The child is now 2¾ years old; the head measures 24 inches in circumference. She has the intelligence of her age; she can